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IMPACT ASSESSMENT OF EXTERNAL THERMAL CONDITIONS ON HUMAN CAPACITY TO PERFORM WORK

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ABSTRACT

This paper describes the initial findings of research work to assess the impact of thermal conditions on the human capacity to do work. Heart rate is considered as a lead indicator of human energy consumption. A laboratory was set up where human volunteers performed standard work routines under controlled conditions. The heart rate of the volunteers was constantly monitored while the temperatures of the laboratory were varied between 5 degrees to 40 degrees centigrade. Data analysis from the initial sample of volunteers shows that the heart rate significantly increases with increase in temperature. The total heart beats which are also an indirect measure of human effort also increases with increase in temperature. Current sample data shows that the inflection points are around 10 degrees and 30 degrees centigrade. The human capacity to do work appears to dramatically drop after 30 degrees centigrade and becomes almost intolerable around 40 degrees centigrade. These initial insights are alarming enough for the industrial engineering practitioners to consider their impact in future workplace layouts and while setting up work standards. There are still many professions which require associates to physically work in open environment under varied thermal conditions and this research will have a significant impact on the way work standards for activities performed by these associates are established. The hypothesis has been statistically validated on the sample data so far and additional samples are leading to further insights.

KEYWORDS: Thermal, Environment, Standards of Work, Pulse Rate, Hear Rate & Work Standards

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Original Article

INTRODUCTION

Commonly available work measurement techniques do not factor the impact of environmental variables like temperature on the work content calculation and the number of associates required for given quantum of work. Environmental conditions in which work is performed are considered out of the scope of the most of research in quantifying the impact on human energy consumption. Environmental variables and their impact on long-term health of the workers and hence productivity are not scientifically quantified and assessed, although their general impact is known. In industries as well as in unorganized sector, the variations in thermal conditions due to seasonal changes are not considered while determining standard output level for the labor and for determination of human resource requirement.

Global warming is a reality and days of extreme temperatures may soon be a norm. Working in these extreme temperatures will require a complete overhaul of the current globally adopted systems of work measurement, work severity, and postural analysis. India is already going through extreme heat wave like conditions and temperatures are at the highest in past few decades. A State like Maharashtra is experiencing very severe temperatures. At the same time, government's GDP growth estimate, Make in India campaign, investments in road,

rail, port infrastructure and logistics are likely to generate more than 5 million new jobs in the next decade. Most of these jobs are likely to be in unorganized or small-scale sectors involving field work in open yards, warehouses, ports, logistics hubs, market yards, etc. With this anticipated growth in the economy, extreme temperatures due to global warming and demand for jobs in the field, it was an opportune time to take up research work to assess the impact of temperature on the human capacity to perform work. Any research which helps understand and quantify the impact of temperature on human energy consumption and devises a system of work content estimation in the varying temperature conditions shall support the cause of estimating the content of work for fair days of work and inhibit inadvertent exploitation of direct labor, especially in field work (non-factory setting).

There are several environment variables which may impact human energy consumption at the workplace like temperature, noise, relative humidity, weight, and others. Considering the practical constraints of setting up of lab, equipment and severity impact of the different environmental variables, it was decided to consider one variable Temperature in this research work.

LITERATURE REVIEW

Whole body vibration and posture as risk factors for lower back pain in forklift drivers were assessed by J. Hoy, N. Mubarak, S. Nelson, et al., (2005) using OWAS and RULA techniques (1). Forklift drivers exposure to two types of whole body vibrations, viz shock loads and sinusoidal vibrations were evaluated. No mention of other environmental factors impacting lower back pain and postural severity were discussed in the paper.

A review of health effects of relative humidity in indoor environments suggests that relative humidity can affect the incidences of respiratory infections and allergies by Anthony V. Arundel, Elia M. Sterling, et al (1996) (2). Experimental studies conducted on airborne-transmitted infectious bacteria and viruses have shown that survival of these organisms is minimized by the exposure to relative humidities's between 40 and 70%. Authors suggest that majority of adverse health effects caused by relative humidity would be minimized by maintaining relative humidity between 40 and 60%. This study does not measure the impact of relative humidity on indoor postural severity and fatigue at workplace.

S. A. Yildizel, G. Kaplan, et al (2015) assessed the impact of heat stress on performance and worker health for a construction site in Moscow (3). Temperatures were varied between 16 to 23 degrees centigrade in two sets of experiments involving more than 193 workers. Impact of temperature on the current efficiency norms was also assessed. No specific quantification of the impact of temperature on work severity in general was established.

Priya Dutta, Ajit Rajiva, et al (2015) assessed the impact of heat on the health of construction workers in Ahmedabad, Gujarat (4).An assessment was a combination of survey questionnaires, focused group discussion, and onsite temperature measurements. This study highlighted the high burden of heat-related discomfort and illness on the construction workers. No quantitative relationship between temperature and work severity was established. Authors suggested that further studies estimating the exact nature of thermal loads experienced by construction workers were essential in the long-term benefit of these workers.

Matt Brearley, Phillip Harrington, et al (2014) undertook a study of electrical utility workers in the northern territory of Australia to examine their physiological and fluid balance responses to climatic conditions (5). An ingestible telemetry pill was used to measure gastronomical temperature and heart rate values were also measured to develop a physiological strain index (PSI). Urine specific gravity, sweat rate and level of dehydration in the workers were also determined

during the study. Authors concluded these workers adhered to the ISO 9886 requirements when undertaking self-paced activity in hot conditions. This is a very good research work and an attempt to quantify the impact of temperature on workers' health and physiological strain is made. Authors recommend more such field studies to extend the impact on broader occupational settings.

Jeremiah Chinnadurai, Vidhya Venugopal, et al (2016) undertook a study of construction workers in Chennai, India to estimate the productivities in construction work under the influence of heat stress using the Predictive Mean Vote (PMI) index (6). Field studies were conducted on the workers and the metabolic rates and workload were determined using ISO 8996. The study showed that working outdoors had a significant adverse impact on productivity to the extent of 35%. There is no impact assessment of temperature on postural severity at work in this research work.

Varsha Karandikar, Shriram Madhukar Sane (2013, 2014) developed P-SVR (Postural State Variation Report) (4, 5) methodology which studies postural severity variations. In this methodology which is based on REBA / RULA, P-SVR index, job difficulty index as well as worker suitability index is also calculated (16). These indexes also consider the time spent and frequency of work elements in different levels of postural severity. Work suitability index also additionally considers three independent variables of age, gender, and proficiency gained at work through the experience of the worker undertaking the job. Varsha Karandikar, Shriram Madhukar Sane (2013, 2014) conducted experiments in a manufacturing setup on different sets of processes. Experiments were conducted on different manufacturing processes in a compressor manufacturing facility. Video analysis along with task elapsed time and occurrence are weighed in the final index of P-SVR. Process Improvement opportunities to reduce the threat level are identified easily as compared to earlier methods. Temperature, noise, relative humidity and other environmental variables are not considered in the calculation of the Postural severity index value as well as most of the existing posture analysis and postural severity analysis tools. Weight greater than 10 Kg is also not addressed sufficiently. Authors evolved an approach to calculate the Job Difficulty Index. This index helps to identify relative difficulty of different jobs being studied. Based on different ranges of this index, tasks can be classified with the sense of urgency required to take corrective actions or do process changes.

Research cited above indicates that more research is required to assess the impact of environment variables on human energy consumption. There are several environmental variables which may impact human energy consumption workplace. Considering the practical constraints of setting up of lab, equipment and severity impact of the different environmental variables, Temperature is considered as the variable for future research.

RESEARCH OVERVIEW

In this research work, an emphasis is been given on quantitatively evaluating the impact of thermal conditions on the human capacity to perform work.

- To conduct laboratory and industrial experiments to assess the impact of thermal conditions on the human capacity to perform work
- To establish a mathematical relationship of temperature on human energy consumption and formulate a new model
- To conduct industrial experiments to validate the model and re-formulate if required

Research Lab and Equipment Specifications

The research laboratory was set up and experiments were conducted on volunteers. The laboratory specifications are shown in Table 1 below.

Table 1: Specifications of the Laboratory

External Size of Chamber	14 Ft X 7.5 Ft X 8 Ft (Height)
Range of Temperature	+2 Deg C to +48 Deg C
Refrigeration Load	9,500 BTU/Chamber
Heating Load	3 KW (For +42 Deg C.)
Panel finish	Pre Painted GI Sheet on both sides
Panel thickness	60 mm
Insulation density	40 Kg/ cum
Floor Insulation	PUF Slab
Floor finish	Aluminium Chequered Sheet with 6 mm marine ply backing
Door Size	34" x 72" (Height) Inches
Door leaf thickness	60 mm thick
Exhaust Fan Size	8" Dia, with side hung window
Refrigeration System	Hermetic compressor – Emerson Copland Condenser with Fan Motors Copper Coils with Al fins Filter Drier Power supply - 230V,1Ph,50Hz Refrigeration Capacity - 10000 BTUH Power Input – 2 HP/Unit

Experiment Protocol

As per the guidelines of the Institutional Ethics Committee (IEC), the following was the experiment protocol being followed.

- Basic medical check-up of volunteers
- Acclimatize at the first set temperature in the lab for 30 mins
- Measure Rest Heart Rate
- Walk on the treadmill set at 3 Miles per hour walking speed for 3 minutes
- Transition to 4 Miles setting on the treadmill
- Walk on the treadmill set at 4 Miles per hour walking speed for 3 minutes
- Get down from treadmill and lie down on the mat and allow the volunteer to recover heartbeat to its original level
- Continue the same procedure at different temperature levels (5, 10, 20, 25 30 and 40 degrees centigrade)
- Refreshment break after approximately 2 – 2.5 hours into the experiment
- At any point in time, if the volunteer wants to withdraw or feels uncomfortable, stop the experiment here and there and not continue after that
- At the end of an experiment, download data from the chest heart rate sensor and upload online

RESEARCH RESULTS

As per the experiment protocol, experiments were conducted on 29 volunteers who were identified to be fit for

doing them**.** Following was the approach adopted for analysis of the sample data.

- Data Cleansing and Outlier Identification
- Treatment of Outlier Data (based on a number of instances (temperature wise) in which outliers were identified for the same volunteer)
- Basic statistical transformations like min, max, average, standard deviation and median on the heart rate, heart rate recovery duration, heart rate recovery in first 2 minutes at the end of the experiment
- Plotting the basic statistics vis-à-vis different temperature groups
- Run statistical significance tests to validate the hypothesis that average heart rate and average heart rate recovery significantly changes at different temperature levels
- Use of t-tests and One way ANOVA
- Run K- means clustering algorithm on the sample data to analyze the clusters formed and additional insights with different variables like AGE, WEIGHT, and other anthropometric data
- Do Co-relation analysis on the sample data
- List insights and findings on sample data

Sample outcomes of the different tests and analyses performed are indicated in figures below. The impact of the change in temperature on rest heartbeat of volunteers is indicated in Figure 1 below. It indicates that there is a significant change in rest heartbeat around 40 degrees centigrade.

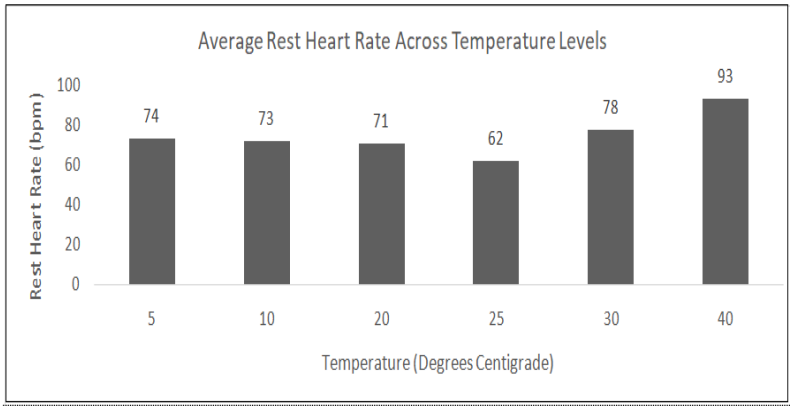

Figure 1: Average Rest Heart Rate across Temperature Levels

The impact of the change in temperature on total heart beats during exercise duration as well as standard deviation of total heart beats is indicated in Figure 2 below. The total number of heart beats is more than 40% at 40 degrees as compared to 20 degrees with standard deviation 4 times that of 20 degrees.

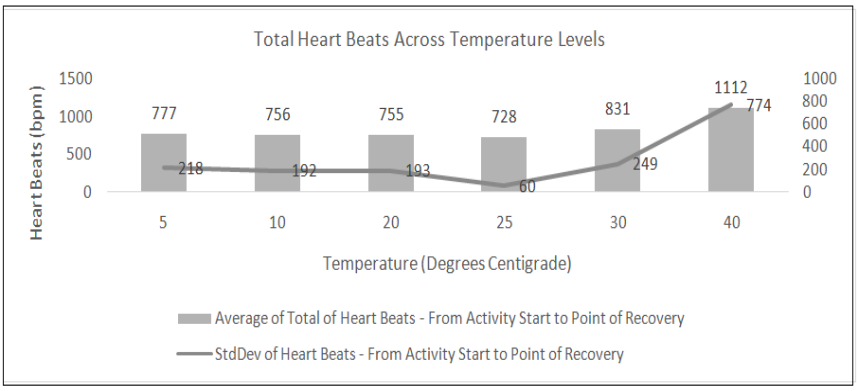

Figure 2: Total Heart Beats and Standard Deviation across Temperature Levels

Co-relation analysis between different variables can be seen in figure 3. It clearly indicates that other anthropo-metric variables like age, height to weight ratio are not having a significant impact on total heartbeats or resting heart rate of the volunteers.

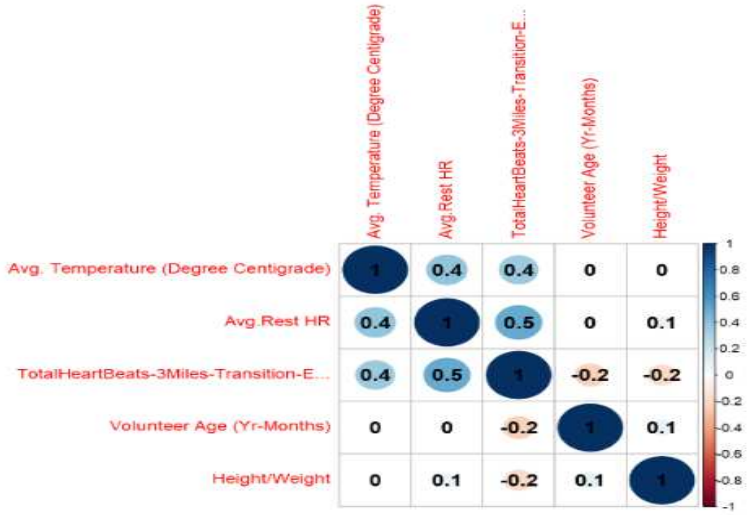

Figure 3: Correlation Analysis between Different Variables

CONCLUSIONS

Experiments conducted so far have shown following insights.

- Very strong positive correlation between heart rate recovery, total heartbeats, rest heart rate and temperature
- There is a significant impact on above variables after 30 degrees C
- Other anthropometric data like height, weight don't show strong co-relations with heart rate

A researcher plans to continue the experiments to cover a larger volunteer sample size and assess the impact of temperature on human energy consumption and capacity to do work.

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